HBR 3160-2

# TECHNICAL PROPOSAL

for

# FEASIBILITY INVESTIGATION

of a

# VIRTUAL OBJECT DETECTION SYSTEM

4 October 1957

HYCON MFG. COMPANY
P.O. Bin "N"
Pasadena, California

SUBJECT: Hycon proposal for Feasibility Investigation of a Virtual Object Detection System

REFERENCE: (1) Hycon proposal for Scientific Research on a Virtual Object Detection System for Over the Horizon Surveillance, dated 8 March 1957

(2) Hycon letter, Subject: "Feasibility Investigation on a Virtual Object Detection System", dated 1 August 1957

(3) Hycon letter, Subject: "Feasibility Investigation on a Virtual Object Detection System", dated 23 August 1957

Dear Sir:

Having contributed to your present interest in the investigation of this promising detection technique, I should like to give you what supplementary information we have that may support your decision to proceed with this significant program.

In preparing our test plan submitted to you with Reference (3), we had looked into some of the physical factors involved in the phenomena which dictate the types of tests to be performed, and to a large extent, determine the type of equipment necessary to make these measurements. Also, to gain an understanding of the physics involved in the phenomena, and to provide us with some order of magnitude as to the size of the detectable virtual body, and a basis for expected detection range, we have made some order of magnitude calculations of expected range. I must admit, however, that although considerable investigation has been made of stellar scintillation for astronomical and meteorological purposes that the theory to provide a basis for calculating the range of detectable disturbance by a supersonic vehicle, is not sufficiently well developed. However, I believe that the estimate of range of a detectable disturbance as shown in Enclosure 1, indicates that this phenomena extends over the range that you are interested in. This estimate of the size of the detectable virtual body served as a basis for the expected detection range increase shown in Figure 4.3 of our proposal, dated 8 March 1957.

Since that time we have put considerable thought into what is very likely the major factor involved in exploitation of this phenomena, and which will certainly have a direct bearing on the range results of the feasibility investigation and test plan submitted to you on 23 August 1957. This key factor, affecting range of detection, is the recognition of this disturbance in the presence of the natural scintillation background. As you realize, the utility of this phenomena does not lie in determining the existence of image disturbance by shock waves, as its short range existence has been confirmed, but lies in the detection range of the disturbance and its recognition in the presence of background scintillation.

There are two test factors which can enhance the recognition of this disturbance. The first factor is connected with the equipment proposed and is concerned basically with the basic equipment sensitivity for this phenomena. We have examined these equipment factors in light of prior observations and believe that we can maximize those factors necessary for repeatable demonstration and detection of the phenomena at the ranges mentioned in the test series.

Because of the prior lack of adequate instrumentation and control of the vehicles that [redacted] has observed, it is difficult to confirm a detection  range from these observations, and his photographic plates. The fact that these plates are not solely his property at this time prevents my forwarding this supporting data to you. However, on one of these plates the lengths of the star trails from the initiation of the trails to the individual disturbances of each track have been measured. These lengths were reduced to time differences and were plotted against the angular position of the disturbed star images. The resulting points graphed a line of uniform slope of angle versus time. This resulting angular rate divided into the speed of sound indicated the vehicle was at a range of some 15 miles and that the detectable virtual body was approximately 1 mile in diameter. It is highly probable that photoelectronic detection means having significantly greater time resolution and higher sensitivity would have done significantly better.

A discussion of those factors which affect the detectability of the photographic equipment and of the photoelectronic equipment, are discussed in further detail in Enclosure 2, and Enclosure 3 of this letter. Such considerations include the importance of aperture size, field of view, detector sensitivity, angular resolution, frequency and time resolution, spectral region, and the Fourier spectrum of natural scintillation. The second major factor which will affect the recognition of the disturbance is the synchronization of the proposed experiments. Naturally, the more closely synchronized the experiments, and the more closely the photographic, and photoelectronic records are marked at the expected time of the disturbance, the better we can recognize the signature against the natural background. Likewise, the greater will be our assurance that the phenomena observed is the desired effect. This synchronization factor is of lesser importance to the photographic recording because of the high degree of correlation that is accomplished visually when looking at many star trails. Natural scintillation, of course, is not correlated over more than a few minutes arc, and this correlation distance should decrease with frequency. Therefore, natural effects can be discriminated photographically from a shockwave whose effect correlates over many degrees of arc.

The required synchronization will be accomplished by existing radar range instrumentation supplemented by either or both pilot announcement of his position over existing markers on the night photo course and/or the use of a spotting telescope at the observation site trained on the running lights of the aircraft.

Although the initial series of tests have been proposed to be performed at Edwards Air Force Base, because of its proximity and because of its night course, and although we feel that sufficient data can be obtained at this test site to substantiate an early exploitation of this phenomena, it is our belief that tests could be performed at alternate test sites such as the Naval Ordnance Test Station at Inyokern, and at Patrick Air Force Base, in Florida. As you may realize, the major portion of the cost involved is in preparing the equipment, arranging for its portability, and in obtaining the initial results. Subsequent tests as may be necessary for further acceleration in exploiting this detection technique would, of course, involve a lower rate of expenditure.

To give you a more appropriate picture of the men who will contribute to this program, I would like to discuss each of them and how their participation will enhance the success of this investigation.

[redacted] STAT

Because the discovery and suggestion of this detection technique originated with [redacted] and because much of his extra time has been spent in exan STAT this [redacted] his interest and knowledge of the field will be an important factor in the success of this investigation. Confirming his interest and that of Hycon's has been our mutual recognition of the potential of this technique and, in addition, our efforts to interest those groups having application for it. I feel that the experience a [redacted] command on this specific phenomen STAT and upon stellar characteristics, is necessary to the early success of this type of an investigation.

[redacted] STAT

Many topics which lie withi [redacted] experience will assist this inves STAT gation of the Virtual Object Detection System, both in fundamental analysis and in practical detail. Part of the work which he conducted while with the Physics Division of NOTS dealt with ultra high speed electro-optical devices, including the application of image tubes as electronic high speed shutters; in addition, he developed a flying-spot photoelectronic microradiometer for use in quantitative spectroscopy. His acquaintance with statistics in physics has occurred in many roles: In the determination of the statistical effect of thermal oscillation in crystals upon their X-ray diffraction patterns; in the application of probability theory and various phases of communication theory to the analysis of submarine detection and acoustic homing; in a theoretical and experimental study of surface wind turbulence and its effect on ground-launched rocket dispersion; and currently, in his analysis at Hycon on automatic mapping instrumentation involving image correlation in two dimensions.

[redacted] (continued) STAT

In addition, [redacted] constant involvement with applied mathematics as head of scientific computing, and subsequently, weapon system evaluation for NOTS, equips him well to assist in the conduct of the project, both in its theoretical phases and in its detailed engineering and data reduction phases. STAT

[redacted] STAT

With Hycon Mfg. Company, he has worked on airborne photographic projects involving advanced mechanical, optical, and photographic problems. His design and field experience in mechanics and optics will be an important factor in the preparation and use of the equipment for this investigation.

[redacted], Physicist STAT

[redacted] has specialized in optical design for the past seven years, although primarily connected with optical design he has been involved in both the laboratory and field testing on a wide variety of photographic and photoelectronic equipment. His experience with large aperture and long focal length optical equipment will directly aid in preparation of the equipment and insure its sufficient optical quantity to implement these tests. STAT

[redacted] B.S. in E.E.; M.S. in Mathematics STAT

The more than seven years experience of [redacted] in electronic development and electronic instrumentation with military communications equipment and missile guidance systems, will insure the adequate selection and assembly of the photoelectronic detection and recording equipment for these tests. [redacted] circuit theory and mathematics background enables him to directly implement the desired amplifier and filtering characteristics necessary to provide greatest discrimination against natural background for optimizing detectivity of the phenomena. STAT STAT

I believe that the men discussed above provide both the experience and judgment and can completely surround the equipment and field test problems involved in this investigation. The development construction and field operations associated with photographic, electronic, optical, equipment in both the visible and infrared spectrum has been one of Hycon's unique skills for the past nine years. As a company, Hycon's experience in this area provides the necessary continuity for the further exploitation and acceleration of this program.

I would like to assure you that my interest in the phenomena discovered and its exploitation first suggested by [redacted] will be my prime responsibility. STAT I trust that the above information confirms our interest in, and our ability to perform, and assists your decision to proceed with this first step in the utilization of this significant discovery.

Very truly yours,

HYCON MFG. COMPANY

[redacted] STAT STAT

Director of Research

Enc. (1) - Estimate of Increased Detection Range

Enc. (2) - Hycon Internal Memo, [redacted] dated 1 October 1957, subject: "Photographic Recording".

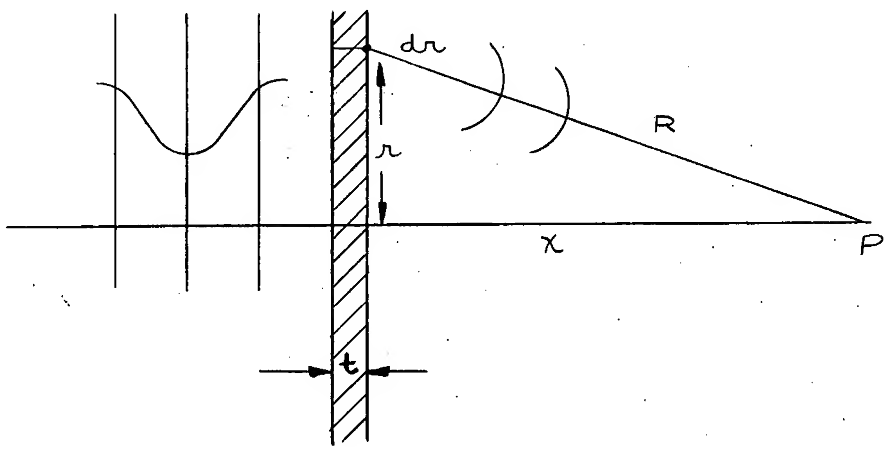
Enc. (3) - Hycon Report, HP-54, entitled, "Considerations on the Use of a Photomultiplier and Telescope for Virtual Object Detection".

# NOTES ON SCATTERING AND REFRACTION BY A SHOCK WAVE - ESTIMATE OF INCREASED DETECTION RANGE

## 1. SCATTERING AND REFRACTIVE INDEX

The fact that the velocity of light in matter is different from that in a vacuum is a result of scattering. The resulting scattered waves from individual molecules interfere with the primary wave bringing about a change in phase which is equivalent to an alteration in wave velocity.

Suppose plane waves strike an infinitely wide sheet of transparent material with a thickness small compared to a wavelength.




The disturbance resulting will consist of the original wave plus the sum of the scattered waves.

The energy scattered by a single atom is proportional to the scattering cross section $\sigma$, which is that part of the area presented by the atom to the oncoming waves which is effective in scattering these waves.

Since the energy is proportional to the square of the amplitude, the amplitude scattered from one atom is proportional to $\sqrt{\sigma}$. If there are N atoms per square centimeter and the sheet has a thickness t, $E_s = \sqrt{\sigma}\, Nt$ the total electric vector at P becomes

$$E + E_s = \sin \frac{2\pi x}{\lambda} + \sqrt{\sigma}\, Nt \int_0^\infty \frac{2\pi r\, dr}{R} \sin \frac{2\pi R}{\lambda}$$

which can be

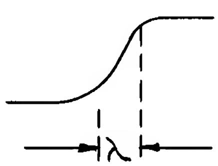
integrated to obtain $E + Es = \sin\left(\frac{2\pi x}{\lambda} + \sqrt{\sigma}\, Nt\lambda\right)$

The phase of the wave at P has been altered by $\frac{\sqrt{\sigma}}{Nt\lambda}$

The presence of a lamina of thickness t and refractive index n retards the phase of a wave by $\frac{2\pi t(n-1)}{\lambda}$ by definition of n.

Thus: $\sqrt{\sigma}\, Nt\lambda = \frac{2\pi(n-1)t}{\lambda}$ and finally $n = 1 + \frac{1}{2\pi} N\lambda^2 \sqrt{\sigma}$ which shows how the refractive index n is related to the number of molecules per cubic centimeter N, to the wavelength $\lambda$ and to the scattering cross section $\sigma$. This can be written for a gas lamina, $n = 1 + G\frac{\rho}{\rho_o}$ where is the density of a gas, $\rho_o$ normal atmospheric density and G is the Gladstone-Dale constant.

## 2. DEVIATION OF A LIGHT RAY PASSING THROUGH A SHOCK FRONT

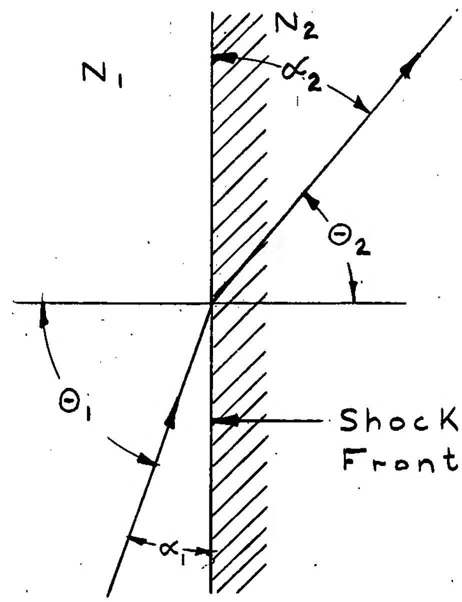



100 lbs. pressure

$\lambda = 10^{-5} - \underline{\underline{10}}^{-6}$ cm

Visible light 500 Å

$\lambda = 5 \times 10^{-5}$ cm




$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$n_1 \cos\alpha_1 = n_2 \cos\alpha_2$$

$$\alpha_1, \alpha_2 \sim 0$$

$$\Rightarrow \cos\theta = 1 - \frac{\theta^2}{2!} + \ldots$$

 (1)

$$n_1\left(1-\frac{\alpha_1^2}{2!}\right) = n_2\left(1-\frac{\alpha_2^2}{2!}\right)$$

$$n_1 - n_2 = -\frac{n_2\alpha_2^2}{2}$$

$$\text{Deviation angle} = \alpha = \sqrt{\frac{2(n_1-n_2)}{n_2}}$$

For a shock front 1 atmosphere above ambient and if we assume that $n = 1 + G\frac{\rho}{\rho_o}$ where $G = .000294$, and $\rho = 2\rho_o$ then $n_1 - n_2 = .000294 \times 2 = 6 \times 10^{-4}$ $n_2 \sim 1$

$$\alpha = (6 \times 10^{-4})^{1/2}$$

$$\alpha = 2.2 \times 10^{-2} \text{ radian}$$

Thus deviation angle, $\alpha$, for this case is about a degree which explains the rather large deviations encountered in shadowgraphs of shock waves.

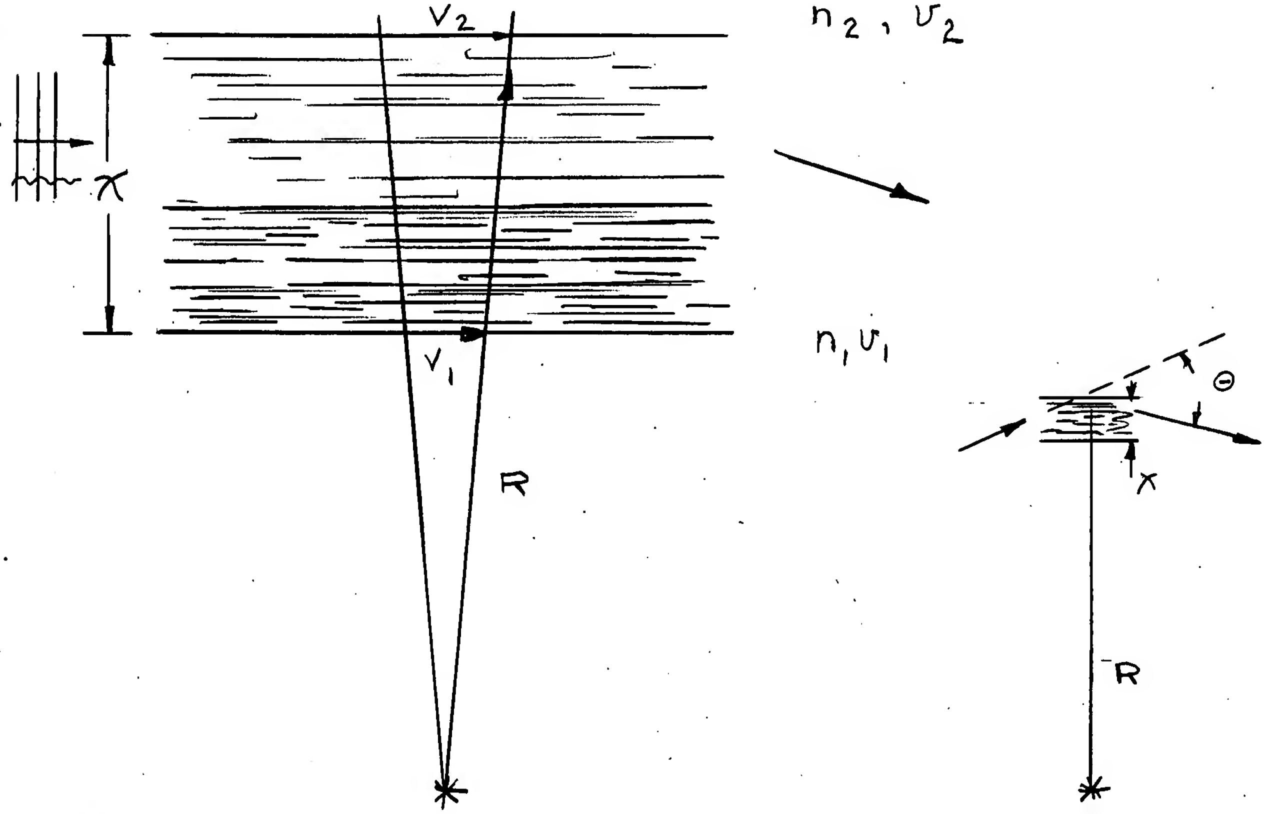
## 3. LIGHT SCATTERING BY TURBULENT FLUCTUATIONS

In a turbulent media the light can be scattered by the vortices and fluctuation in the media. This effect causes the scatter propagation noticed with microwaves. The fluctuations in density do not seem to be so important as the fluctuations in humidity. (Villars and Weiskopf - 7). For radio waves it has been studied also by Booker and Gordon - 6. The fluctuations deviate the ray, and also cause the energy to be scattered out of the principal ray into a narrow cone.

The angular size of the cone depends on the mean size of the turbs, the theory is in rather poor shape at present.

 e (1)

## 4. DERIVATION OF EQUATION FOR DEVIATION OF LIGHT RAY IN DENSITY GRADIENT




$$\frac{v_2}{v_1} = \frac{R}{R-x}$$

$$(R-x)v_2 = Rv_1$$

$$R(v_2 - v_1) = xv_2$$

$$R = \frac{xv_2}{v_2 - v_1}$$

Substituting for the refractive index $R = \dfrac{\frac{x}{n_2}}{\left(\frac{1}{n_2} - \frac{1}{n_1}\right)} = \dfrac{\frac{x}{\cancel{n_2}}}{\frac{n_1 - n_2}{n_1 \cancel{n_2}}}$

Therefore: $\dfrac{1}{R} = \dfrac{n_1 - n_2}{x} \dfrac{1}{n_1}$ in the limit where $x \rightarrow o$, $\dfrac{n_1 - n_2}{x} \longrightarrow \dfrac{\partial n}{\partial x}$

$$\frac{1}{R} = \frac{\Delta n}{n}$$

Suppose for simplicity we let the stellar line of sight be normal to the gradient then $\frac{1}{R} = \frac{\text{grad } n}{n}$ if n has only an x component of variation

$$\frac{1}{R} = \frac{1}{n}\frac{\partial n}{\partial x}$$

$$\frac{ds}{R} = \frac{ds}{n}\frac{\partial n}{\partial x}$$

letting ds = dx

$$\frac{ds}{R} = d\theta = \frac{\partial n}{n}$$

$$\theta = \ln n - \ln n^1$$

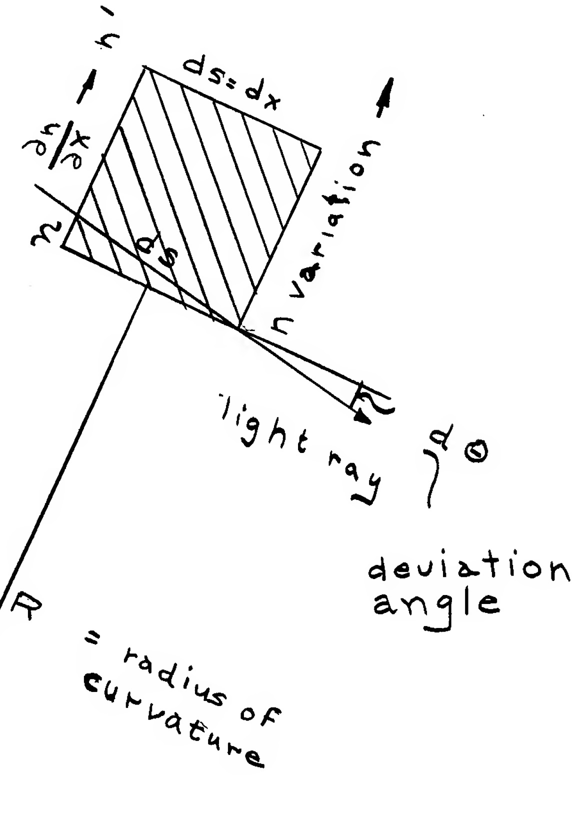
$$n = 1 + K\rho$$

$$\therefore \ln n \simeq K\rho$$

$$\therefore \theta = K(\rho - \rho^1) \text{ where}$$

$$K = \frac{0.000294}{\rho^o}$$

$$\theta = 0.000294 \frac{(\rho - \rho^1)}{\rho^o}$$




If we assume that our optical instrument is capable of detecting a 1 second of arc deviation, then we may calculate the density gradient producing it.

$$\theta = 1 \text{ second} = \frac{1}{60 \times 60 \times 60} = \frac{1}{216000} \text{ radian}$$

$$\frac{\rho - \rho^1}{\rho^o} = \frac{1}{216000 \times .000294} = \frac{1}{63.5} \approx 1.5 \times 10^{-2}$$

Therefore the density gradient producing 1 second of arc deviation must be

$$\frac{d\rho}{\rho_o} \approx 1.5 \times 10^{-2} \text{ for } ds = dx$$

However, in the more general case the shock radius is sufficiently large such that the light should traverse a path length through the shock gradient many times the thickness of the gradient.

Thus for $ds = 10\, dx$ $\qquad \frac{d\rho}{\rho} \approx 1.5 \times 10^{-3}$

$ds = 100\, dx$ $\qquad \frac{d\rho}{\rho} \approx 1.5 \times 10^{-4}$

$ds = 1000\, dx$ $\qquad \frac{d\rho}{\rho} \approx 1.5 \times 10^{-5}$

## 5. ESTIMATE OF SUPERSONIC AIRCRAFT DETECTION RANGE

Let us assume that the energy in a shock wave decays exponentially at long distances from the source and that the supersonic aircraft produces a shock wave of one atmosphere amplitude ($10^6$ dynes/cm$^2$). Such an aircraft is just audible at 10 miles. Since the threshold of hearing is $2 \times 10^{-4}$ dynes/cm$^2$, the wave has thus decreased in amplitude 10 orders of magnitude in ten miles.

If we assume that it decays at the rate of an order of magnitude per mile, then it will decay 3 orders in 3 miles.

This pressure will then be $10^3 \dfrac{\text{dynes}}{\text{cm}^2}$

$$\frac{d\rho}{\rho} = \frac{d\rho}{\rho} = 10^{-3}$$

Thus from paragraph 4 for a value of ds=10dx the estimated radius of the detectable virtual body would be three miles. This would correspond to an increase in the detection horizon (using the approximate horizon formula, $D = \sqrt{2h}$ where D is in miles and h is in feet) of D $\sqrt{32000} \approx$ 175 miles.

## 6. REFERENCES


a. "Deflection and Diffusion of a Light Ray Passing Thru a Boundary Layer." H. W. Liepmann Report 5M-14397 Douglas Aircraft Co.

b. "Appreciation of Scattering Theory to Measurement of Turbulent Density Fluctuations by an Optical Method." H. A. Stine and W. Winovich TN 3719 NACA

c. "A Preliminary Consideration of Air Turbulence on Definition in Aerial Photography" D. E. MacDonald Boston University Tech Rep 54 June 1954

d. "Refraction Errors in Aerial Photography at High Flight Speeds." M. P. Moyle, R. E. Cullen. Quarterly Prog. Rept. #2 31 Oct 1954, 31 Jan 1955. Contract AF 33(616) - 2268, Rept. Unclassified 24/h2

e. "Some Notes About the Deviation of a Light Beam Passing the Disturbed Density Field Surrounding a Fast Flying Aircraft." Otto Walchner, W. Rambauske Memorandum Rept. MCREOS/OW/WR/RCM Serial No. MCREOS 48-1

f. Booker, H. G. ; Gordon, W. E. "A Theory of Radio Scattering in the Troposphere." Proc. IRE Vol 38 #4 April 1950

g. Villars, F. and Weiskopf, V. F. "The Scattering of Electromagnetic Waves by Turbulent Atmospheric Fluctuations." Phys Rev Vol 94 #2 April 15, 1954

h. Stanton and Ritter. Report on "Shock Wave Photography by Light Blink Method Using GR Camera." Nots Tech Memo - 1949

i. Northrop Snark Star Tracker Reports On Image Quality Reduction Through Boundary Layer Scattering.

Enclosure (2)

# M E M O R A N D U M

1 October 1957

TO: W. Q. Nicholson

FROM: P. Rosenblum

SUBJECT: Photographic Recording for Virtual Object Detection System

1. Since we last discussed the availability of photographic equipment that could be used for the initial tests of the Virtual Object Detection System, we have found that two additional pieces of equipment, (items 2 and 3 below) are available to us at an early date. Both of these equipments will be more suitable than item 1 from the standpoint of number of stars recorded and streak rate. The available equipments are:

| | Lens | Camera | Format Size |
|---|---|---|---|
| 1. | 3" D, 24" F.L., f/8 | K-17 | 9" x 9" |
| 2. | 8" D, 40" F.L., f/5 | K-17 | 9" x 9" |
| 3. | 10" D, 80" F.L., f/8 | Jonel | 2-1/4" x 2-1/4" |

Some of the problems of determining the quantity and type of information which can be recorded with an experimental photographic set-up using this existing or slightly modified equipment are as follows:

(a) Determine the number of stars which will be photographed by available equipment. The greater the number of stars recorded, the better the correlation can be expected in determining magnitude and nature of the disturbance.

(b) Determine the streak rate which will allow adequate time discrimination.

2. The mean average density of stars in the sky by magnitude is tabulated in Table 1. For a camera field 13° square (40" F.L., 9" x 9" format) the cumulative total to 5th magnitude stars is on the average of seven stars. Smaller camera angles necessitate photographing fainter stars (higher stellar magnitude) to obtain a sufficient number in the camera field. However, assuming we need be interested in stars no fainter than 5th magnitude, we can evaluate the available equipment.

3. In order to determine the maximum streak rates which can be used, the relationship between streak velocity, lens aperture, and star magnitude is derived as follows:

$$① \quad m_2 - m_1 = 2.5 \log\left(\frac{I_2}{I_1}\right)$$

where: M = magnitude

I = light intensity from star

$$② \quad \text{and:} \quad \frac{I_2}{I_1} = \left(\frac{D_2^2}{D_1^2}\right)\left(\frac{V_1}{V_2}\right)$$

where: D = lens diameter (in)

V = streak velocity (in/sec)

$$\text{then:} \quad \frac{I_2}{I_1} = \log\left(\frac{D_2^2}{D_1^2}\right) + \log\left(\frac{V_1}{V_2}\right)$$

$$= 2\log\left(\frac{D_2}{D_1}\right) + \log\left(\frac{V_1}{V_2}\right)$$

$$\text{Substituting:} \quad m_2 - m_1 = 5\log\left(\frac{D_2}{D_1}\right) + 2.5\log\frac{V_1}{V_2}$$

$$③ \quad m_2 = 5\log\left(\frac{D_2}{D_1}\right) + 2.5\log\frac{V_1}{V_2} + m_1$$

In order to establish a base reference for one set of conditions for the above formula, we photographed a star field including the Pleiades and the Hyades on a Tri-X Panchromatic plate using a Wollensak 3-1/4" aperture, 17" F.L., 5" x 7" plate size (see Figure 1). The star images were streaked by their own diurnal motion.

Stars as faint as 7th magnitude gave easily detected streaks. Thus, we have established the reference conditions:

$D_1$ = 3.25" (Lens aperture)

$V_1$ = .00107"/sec (Streak velocity)

$M_1$ = 7 (Faintest stellar magnitude detected)

$$\text{or} \quad m_2 = 5 \log \frac{D_2}{3.25} + 2.5 \log \frac{.00107}{V_2} + 7$$

If we wish to detect 5th magnitude stars with an 8 inch diameter lens

then $m_2 = 5$ and $D_2 = 8''$

and $V_2 = .017''/\text{sec}$ (streak velocity)

This is over six times the diurnal motion for a 40" F. L. lens. We can expect to increase this permissible rate by using special high speed emulsions, or limiting higher streaking rate tests to brighter (and fewer) stars.

4. . The equipment which is preferable for the initial tests from the standpoint of availability and size is the 40" f/5 Baker lens using an A-9B (9" x 9") Magazine. This high quality cartographic lens can be obtained locally and comparative optical bench tests made to select the best lens from a number of them that are available. Our A-9B, I. M. C. Magazine can be modified to provide adequate smoothness (less than 1% velocity variation) for a variable speed film transport.

A pulsed timing light can be inserted in the camera magazine to provide time reference marks on the film. Star patterns may be identified for time reference by momentarily capping the lens.

The field of this camera with the Baker lens will provide a minimum of seven star trails using .017 inches/sec film velocity (about seven times the stellar diurnal motion). This should be adequate for correlation on the initial tests.

It would also be desirable at greater ranges to have available the 80" F. L. f/8, 2-1/4" x 2-1/4" Jonel Mirror Lens. This high resolution cinetheodolite lens is available from John H. Ransom Laboratories.

The larger aperture and higher resolution of this lens will allow a finer time discrimination in the streak image, or by slowing the streak velocity, fainter and hence, more star trails may be recorded to fill the narrower field angle.

STAT

TABLE 1 - Average Star Density

| Magnitude | No. Stars | Cumulative | Mean Average (sq. degrees/star) |
|---|---|---|---|
| 1 | 20 | 20 | 2060 |
| 2 | 65 | 85 | 486 |
| 3 | 190 | 275 | 150 |
| 4 | 425 | 700 | 59 |
| 5 | 1100 | 1800 | 23 |
| 6 | 3200 | 5000 | 8.3 |
| 7 | 8200 | 13200 | 3.1 |
| 8 | 22800 | 360000 | 1.15 |
| 9 | 62000 | 98000 | 0.42 |
| 10 | 166000 | 264000 | 0.15 |
| 11 | 431000 | 695000 | 0.017 |

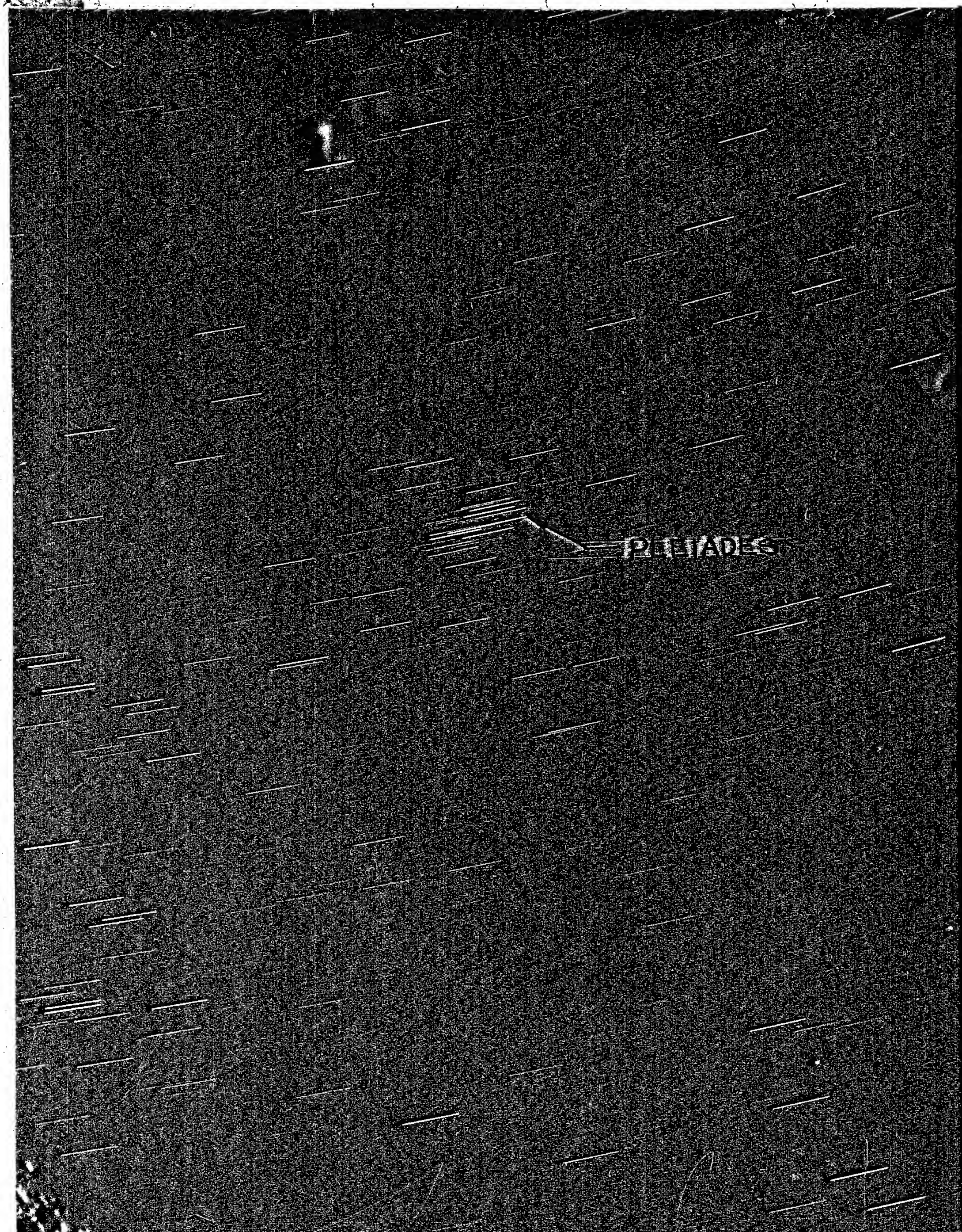



Figure 1

Star Trails showing Pleiades and Hyades. Taken with: Wollensak Camera - 3-1/4" aperture, 17" F.L., 5" x 7" Tri-X Panchro Plate. Exposure: 5 minute, diurnal motion only.



# Considerations on the Use of a Photomultiplier and Telescope for Virtual Object Detection

## GENERAL

This memorandum discusses the problems involved in the use of a photomultiplier telescope and recording system for the purpose of detecting the perturbation of star images due to weak atmospheric shocks. As has been proposed by Dr. Zwicky, objects of military interest which create growing shock configurations may be detected at long ranges by the effect which the "virtual objects" produce on discrete star images. The phenomena involves both displacement of the image and modulation of intensity, depending on the detailed mechanism of the interaction between the shock front and the light wave front.

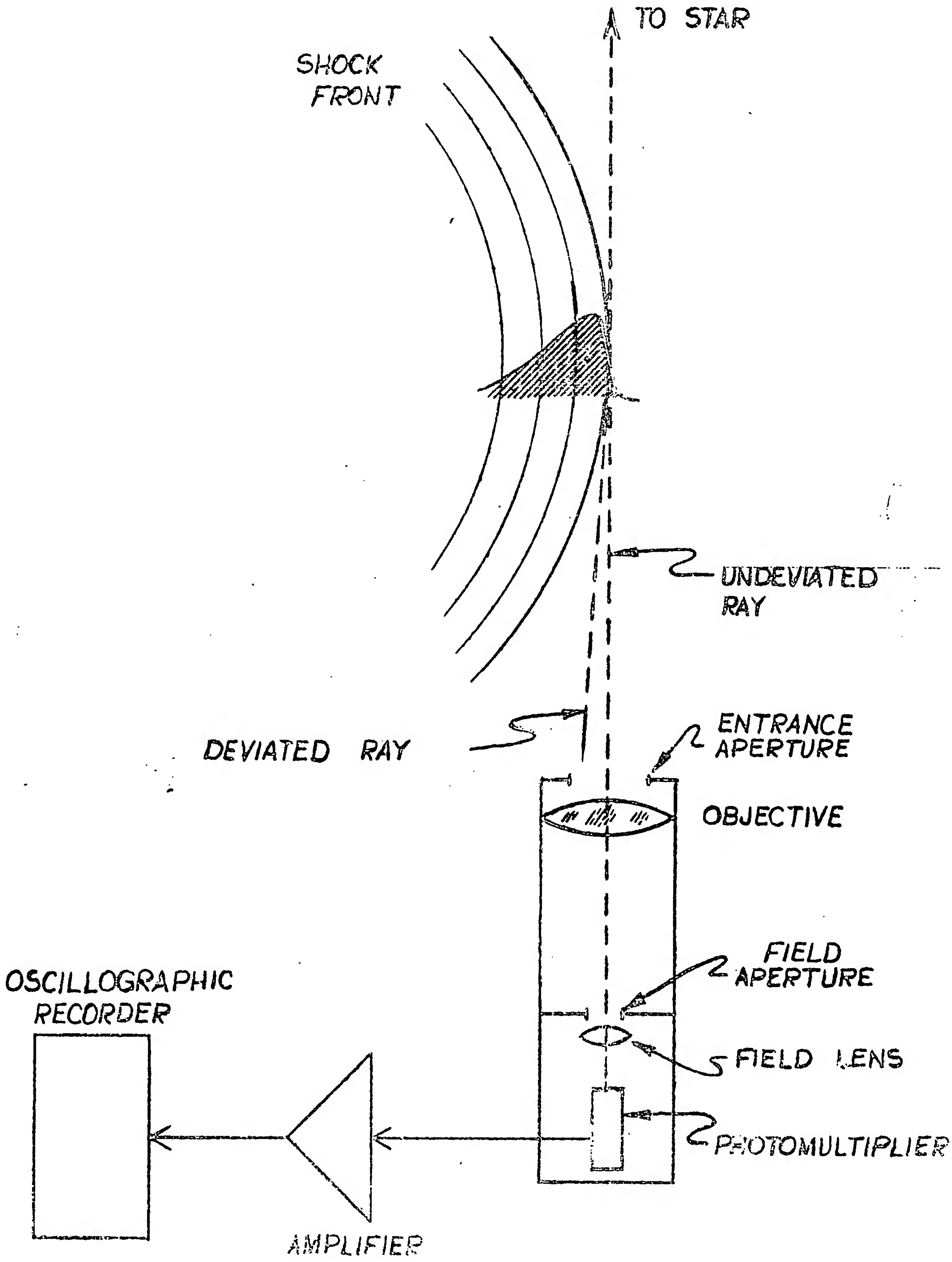
The experimental configuration is illustrated in Figure 1. As the shock front becomes tangent to the light ray from the star, the wave front of the light is perturbed with the result that the star image is altered. The nature of the alteration of the image depends on the spatial distribution of the matter which constitutes the front. If the spatial scattering structure is non-stochastic in character, coherent scattering occurs and image formation is not significantly impared. The image may be moved or distorted; this effect is associated with refraction.

If the scattering structure possesses only a radial distribution function, and is random in its nature, the scattering results in a statistical superposition which no longer possesses phase. The result of such scattering is to diffuse the image rather than to displace it.

Since the shock phenomena are both highly transient and discontinous in nature, it is expected that the interaction of shock waves with stellar rays will produce both the refractive effect of displacement and the scattering effect. For purposes of detection, it is desirable that the total received energy vary markedly with the passing of the shock. Since the refractometer effect (that of occulting the objective) and the scattering effect (that of scattering the image out of the aperture) both lead to energy loss, the received energy can be expected to vary, regardless of the detailed mechanism.

## STELLAR SCINTILLATION

The proposed experiments might be considered an extension of the phenomenon of stellar scintillation, which is due to the disturbance of the star wave fronts by turbulent blobs and other atmospheric inhomogeneities. By the same token, natural stellar scintillation is the background against which we must detect disturbance by the virtual object. We should, therefore, optimize the equipment for discriminating against natural scintillation to extend detection of the virtual object effect.


TO STAR
SHOCK FRONT
UNDEVIATED RAY
DEVIATED RAY
ENTRANCE APERTURE
OBJECTIVE
FIELD APERTURE
OSCILLOGRAPHIC RECORDER
FIELD LENS
PHOTOMULTIPLIER
AMPLIFIER

## STELLAR SCINTILLATION (continued)

Much work has been done on stellar scintillation. An excellent summary of this work has been published by F. Nettelblad in 1953, (Reference 1). The results of his investigations substantiate that scintillation is the result of localized perturbations of the wave front due to atmospheric inhomogeneities. The magnitude of the scintillation is dependent upon zenith distance, telescopic aperture, and atmospheric conditions. The fluctuations are greater if the star is observed through a filter, because the averaging of chromatic paths through uncorrelated scattering regions is thus eliminated. The amplitude of spectral components of scintillation decreases with increasing frequency. We should make use of these dependencies to optimize the detection of weak shocks in the presence of the noise background of natural scintillation.

## OBJECTIVE SIZE

A large objective favors photoelectric observation by admitting a large number of photons. The time of observation (or time constant) over which the collected photons are averaged must embrace a sufficient number of arrivals to hold the shot-noise to an acceptable level. Further, a large objective reduces scintillation through spatial averaging. Since we seek to supress natural scintillation rather than to observe it, it is apparent that we should increase the objective diameter until we begin to also average out the perturbations due to the shock front. Since the dimensions of such perturbed regions are not fully known, it is difficult to estimate the optimum size for the objective. However, a report by Cassen and Ritter indicate that the thickness of a conical shock at greater distances increases as the square root of time after initiation. Thus, shock thickness should be approximately the square root of its radius. This would allow use of a relatively large objective, say, 10 inches or larger.

J. S. Hall (Reference 2) has reported that natural scintillation decreases linearly with aperture above ten inches. It is also reported that the amplitude increases for much smaller apertures (3 inches). The measure of the effect has been confused by inadequate statistical definition of the quantities to be measured. The computation of estimates is made difficult by the expression of scintillation in the form of "Upper Limit of Scintillation", rather than in meaningful moment form.

For example, Whitford and Stebbins (Reference 3) found that ±40% scintillation was obtained by using a 50 millisecond averaging time with a 4 inch aperture; thus, in order to reduce natural scintillation to, say, 5%, the aperture must be increased to 32 inches. Another set of experimental observations gave ±6% for a 60 inch aperture. On this rough basis we may expect ±16% natural scintillation with a 10 inch objective when averaged over 50 millisecond periods. Much higher fluctuations were obtained by Butler (Reference 4) with a 15 inch aperture and one millisecond averaging time. However, the units are not comparable.

## AVERAGING TIME

The averaging time has an effect upon observed scintillation magnitude which depends upon the frequency spectrum of scintillation. Gifford and Mikesell (Reference 5) have determined the spectrum of the scintillation of Vega observed through a 4 inch telescope by determining the fluctuation power in a 6 cycle bandwidth centered variably below 120 cycles per second. The observed amplitude is inversely proportional to frequency except for the frequency range below 10 cps; it appears that the use of a 6 cps bandwidth below 10 cps renders the results at the low frequency end inconclusive. Because of the 1/f character of the spectrum, practically all of the natural scintillation fluctuation power is contained in the frequency band below about 100 cps. It is therefore possible to also discriminate against the scintillation background by using a high pass filter which rolls off below about 100 cps. To avoid the noise inherent in excessive bandwidth, it is also desirable to cut off the upper end in the vicinity of a thousand cycles; shaping of the filter characteristic can minimize oscillatory response. The use of such a filter will enhance the detectability of rapid changes due to shock fronts against the natural scintillation background. Were the spectra of both scintillation and the shock response fully known, the detection process could be optimized by techniques used by Wiener (Reference 6).

## APERTURE SIZE

In photoelectric observation of a star, it is necessary to use an aperture or pin hole through which the star image is focussed in order to eliminate light from adjacent stars and, more specifically, the night sky. The aperture must be small enough to minimize background light but large enough to insure that the star stays within the aperture.

The smoothness of the telescope drive is very important in determining the optimum aperture, since the variance of the star image location is the sum of the mean square drive error and the mean square displacement due to scintillation. Further, it will be recognized that a given aperture corresponds only to a certain small probability of escape of the image from the detector area. Realistic measures of "detectability" must also be in probabilistic terms. Woodward (Reference 7) discusses this matter clearly in connection with the detection of radar signals in noise; the use of "inverse probability" provides an analytical basis which is well matched to human experience and understanding.

The selection of the optimum aperture for detection of weak shocks in the presence of stellar scintillation depends upon:

1. "Seeing" conditions
2. Star magnitude
3. Drive smoothness

APERTURE SIZE (continued)

4. Image motion statistics due to scintillation.

5. Observing time as determined by filtering.

6. The statistics of shock signatures.

The last item in the list is largely unknown and is very difficult to predict in a practical sense, both because of uncertainty in the statistics of the theoretical model, and because of the widely varying aspects which the shock may assume relative to the observer in different experiments. Thus, typical shock signatures can best be sought through experiment.

The contributions of scintillation to aperture diameter may be judged by the rule-of-thumb used at Palomar: two seconds of arc plus twice the seeing diameter of the star under observation. Since seeing is in the region of 1 to 4 seconds of arc, the aperture should be in the range of 4 to 10 seconds of arc, or greater, as limited by the smoothness of the clock drive.

COLOR FILTERING

The stellar scintillations observed simultaneously in different color bands are relatively uncorrelated, presumably because the rays leading to the formation of stellar images follow adjacent but different paths through the scattering structure. The color distinctions are reported to diminish rapidly with increasing objective diameter, indicating that the effect is small scale. However, all scintillation effects show this dependence on objective size.

For the detection of sharp wave fronts, such as occur in atmospheric shock waves, it is conceivable that the blue rays, for example, might be refracted out of the objective while the red ones were not yet affected, resulting in a convolution, or smearing out, of the shock effect. Color filtering should be used, therefore, despite the light loss, to improve the experimental resolution. We should count on the size of the objective to reduce the unwanted enhancement of natural scintillation by color filtering while using it to improve the sharpness of response to shock refraction. A filter providing blue transmission should be considered first.

ELECTRONIC PHOTOMULTIPLIER

The star image in the plane of the aperture should be diffused upon the photo emissive surface.

ELECTRONIC PHOTOMULTIPLIER (continued)

The light energy by star magnitude is as follows:

$$m = -2.5 \log_{10} \frac{I}{I_o}$$

where $I_o = 3.1 \times 10^{-13}$ watts/cm$^2$ (Reference 8)

At 0.556 microns, one watt is equal to 621 lumens. Morton et al (Reference 9) give the constant of proportionality between brightness and photon emission as $1.3 \times 10^{16}$ photons per second per lumen.

Vega is reported to be $0.^m1$ with respect to S-4 photosurface (Reference 8); the corresponding incident energy is then $2.8 \times 10^{-13}$ watts/cm$^2$ or $1.75 \times 10^{-10}$ lumens/cm$^2$. Assuming an objective area of 1275 cm$^2$ (10-inch diameter), one collects $2.18 \times 10^{-7}$ lumens, corresponding to $4.8 \times 10^6$ photons per millisecond. The photon shot noise is thus very small, approximately 0.05%.

The efficient photocathodes yield 50-100 microamperes per lumen (Reference 9), 40 microamperes per lumen for the lower noise 1P21 photomultiplier (Reference 10). The current gain achieved is $2 \times 10^6$. Thus, the anode current yield is about 80 amperes per lumen. For Vega viewed through a 10 inch objective, one obtains an anode photocurrent of approximately 16 microamperes.

The equivalent noise input for the 1P21 photomultiplier is $5 \times 10^{-13}$ lumens per cycle of bandwidth. A bandwidth of 1000 cycles per second is thus associated with $5 \times 10^{-10}$ lumens equivalent noise; the signal-to-noise ratio is about 1000. This indicates that from an E.N.I. standpoint that the smaller objectives and lower magnitude stars will be permitted.

Added to the photon noise and the photomultiplier dark current fluctuation is noise arising from the variable secondary electron yield in the photomultiplier. The origin of this noise has been discussed by Morton (Reference 10), and by Pierce (Reference 11); the approximate result of this is that the input mean square fluctuation is multiplied by the factor

$$\frac{N}{N-1}$$

Where N is the average stage gain (5 for the 1P21). Thus, the secondary emission statistics increase the root mean square fluctuation by a factor 1.12. Not a significant amount.

The combined photomultiplier output capacitance (6.5 micro-microfarads) and input plus stray capacitance may be estimated to be about 15 micro-microfarad. The 1000 cycle bandwidth thus allows the use of 10 megohms as the input resistor; so large a value would be necessary only for stars approaching the 10th magnitude. One megohm provides a root mean square noise amplitude of 4.1 microvolts; the

signal is about 16 volts for this load, and it is apparent that Johnson noise is unimportant in this case. Indeed, it appears that even 10th magnitude stars will not suffer noise wise from this source.

(Reference 1) - Studies of Astronomical Scintillation by F. Nettelblad, published by the Observatory, Lund, Sweden, 1953.

(Reference 2) - Astronomical Seeing, Proc. of Natl. Sci Foundation, Astronomical Photoelectric Conference

(Reference 3) - Whitford, A. E. and Stebbins, J., Photo-electric measurements of the scintillation of stars. Publ. AAS 8, 228, (1936)

(Reference 4) - H. E. Butler, Observatory FO, 235-237 (1950) Recordings of Scintillation

(Reference 5) - Atmospheric Turbulence and the Scintillation of Starlight, Weather, July 1957, F. Gifford, and A. H. Mikesell

(Reference 6) - N. Wiener: Extrapolation and Smoothing of Stationary Time Series, Massachusetts Institute of Technology Press

(Reference 7) - P. M. Woodward: Probability Theory and Information

(Reference 8) - American Institute of Physics Handbook

(Reference 9) - Morton, Ruedy, Krieger: The Brightness Intensifier, RCA Review 9 (September 1948) 419-32

(Reference 10) - G. A. Morton: Photomultipliers for Scintillation Counting RCA Review 10, (December, 1949) 525-553

(Reference 11) - J. R. Pierce: Noise Resistances and Electron Streams: Bell System Technical Journal 2F (January, 1948) 158-174